United States
Department
of Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-398

September 1991

Insect Infestation of Fire-Injured Trees in the Greater Yellowstone Area

Gene D. Amman[1]
Kevin C. Ryan[2]

ABSTRACT

Permanent plots were established in the Greater Yellowstone Area (GYA) following the 1988 fires to determine response of bark beetles to fire-injured conifers. Within 2 years (1989 and 1990), 67 percent of the Douglas-fir had been infested by bark beetles (primarily the Douglas-fir beetle) and wood borers; 44 percent of the lodgepole pine were infested (primarily by the pine engraver); 82 percent of the Engelmann spruce were infested (mostly by spruce beetle); and 71 percent of the subalpine fir were infested (mostly by wood borers). Bark beetle infestation usually occurred in trees having 50 percent or more basal girdling by fire. However, uninjured Douglas-fir also had 46 percent of the trees infested in 1990. The large proportion of uninjured Douglas-fir that was infested by Douglas-fir beetle in 1990 suggests infestation will increase in unburned portions of the GYA. Of the trees that died, a fire-injury model correctly predicted death for one-half of the Douglas-fir and two-thirds of the lodgepole pine, but all of the Engelmann spruce and subalpine fir.

KEYWORDS: *Pseudotsuga menziesii, Pinus contorta, Picea engelmannii, Abies lasiocarpa, Dendroctonus pseudotsugae, Ips pini, Dendroctonus rufipennis,* Cerambycidae, Buprestidae, *Dendroctonus ponderosae*

Survival of conifers following fire depends on the type and degree of injuries sustained, initial tree vigor, and the postfire environment, including weather and insect and disease population dynamics (Ryan 1982, 1990). As fire injuries increase, the probability of tree death increases. Numerous authors (compare Peterson 1985; Peterson and Arbaugh 1986, 1989; Ryan 1990; Ryan and others 1988) have identified the proportion of crown killed as the key injury contributing to death of most trees, but injuries to bole cambium or roots or both may dominate in some cases (Ferguson and others 1960; Ryan and others 1988; Ryan and Reinhardt 1988). Resistance to cambium injury increases with the square of the bark thickness (compare Martin 1963; Peterson and Ryan 1986), which in turn increases approximately linearly with diameter (Ryan and Reinhardt 1988). Multiple injuries are common and increase the likelihood of death (Furniss 1965; Ryan 1990; Ryan and others 1988; Wagener 1961). Mortality resulting from crown kill is often apparent by the end of the first growing season following fire, while death resulting from bole and root injury often does not become apparent before the second growing season (Ferguson and others 1960; Ryan and others 1988; Ryan and Frandsen 1991).

Bark beetles and wood borers are frequently associated with tree mortality following fire. However, it is difficult to adequately assess fire injuries, particularly to the bole and roots. In the absence of significant bole or root injuries, the probability of attack by primary bark beetles is initially low with light defoliation, increases with moderate to heavy defoliation, and often declines with complete defoliation (Furniss 1965; Miller and Keen 1960; Mitchell and Martin 1980; Wagener 1961). Bark beetles also attack trees with cambium injury but are thought to contribute little to mortality, except in conjunction with defoliation or when a large proportion of the

[1]Project Leader, Mountain Pine Beetle Population Dynamics research work unit, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, located at the Forestry Sciences Laboratory, Ogden, UT.

[2]Research Forester, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, located at the Intermountain Fire Sciences Laboratory, Missoula, MT.

circumference is killed (Ferguson and others 1960; Ryan and Frandsen 1991; Wagener 1961). Secondary bark beetles (those commonly attracted to severely weakened or recently killed trees, as opposed to primary bark beetles that can infest and kill healthy trees) and wood borers are commonly attracted to burned trees, but their contribution to mortality, while thought to be minor (Mitchell and Martin 1980), is largely unknown.

Ryan and others (1988) reexamined conifers 8 years after burning and demonstrated the importance of bole injury in predicting survival. Percentage crown scorch, degree of cambium injury, and diameter were the best predictors of survival for those trees. Wyant and others (1986) also found that percentage of crown scorch and tree diameter were the best predictors of Douglas-fir survival. Peterson and Arbaugh (1986) found percentage crown scorched and percentage basal circumference scorched were the best predictors of lodgepole pine survival in the Northern Rocky Mountains. They showed crown scorch and the level of insect attack were most important as predictors of survival of Douglas-fir. However, they did not identify the insects causing tree mortality. In contrast, Peterson and Arbaugh (1989) observed that insect attack was not a significant variable in predicting the fate of fire-injured Douglas-fir in the Cascade Mountains, possibly because insect populations were low.

Several recent studies have modeled postfire survival of Northern Rocky Mountain conifers. Ryan and Reinhardt (1988) modeled postfire survival of seven Northern Rocky Mountain conifer species. They used percentage crown scorch as the only injury variable, and bark thickness, calculated from species and diameter and used as a measure of resistance to cambium injury, to predict the fate of burned trees. Bevins (1980) modeled postfire survival of Douglas-fir 1 year after burning using tree diameter and scorch height as predictive variables.

Although our understanding of fire-caused mortality has improved and application models have been developed for predicting the fate of fire-scorched conifers in the Northern Rocky Mountains, the relationship of insects to fire injury is still not well understood. In the aforementioned studies, insects attacked trees to varying degrees, but their contribution to mortality and host/insect species relationships was not determined. The degree to which fire-injured trees lead to a buildup of populations capable of attacking nearby unburned trees also has not been determined for most species. Therefore, studies were started in the Greater Yellowstone Area (GYA) in 1989 following the large fires that occurred in 1988 to determine (1) rate of bark beetle infestation of fire-injured trees; (2) change in infestation behavior from fire-injured to uninjured trees; and (3) bark beetle and wood borer infestation in relation to degree of individual tree injury.

Forest fires in the Greater Yellowstone Area (which consists of Yellowstone National Park and adjacent lands) severely charred millions of trees, instantly killing them. Countless others were defoliated, girdled, or partially girdled by heat (fig. 1). Fire-killed and injured trees provide infestation opportunity to bark beetles and wood-boring insects (Fellin 1980; Furniss and Carolin 1977) when populations exist in the vicinity of the fires.

Figure 1—Trees girdled or partially girdled by heat in 1988, Yellowstone National Park.

Bark beetle surveys in the GYA suggest that all species were at low population levels at the time of the 1988 fires, with the exception of the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) (DFB). The massive infestations of mountain pine beetle (*D. ponderosae* Hopkins) (MPB) that covered over 965,000 acres in Yellowstone Park in 1982 had declined to only 310 acres by 1986 (Gibson and Oakes 1987) and to no infested trees in 1987 (Gibson and Oakes 1988). In the nearby Bridger-Teton National Forest, MPB infestation declined from 3,224 trees in 1987 to 890 trees in 1988 (Knapp and others 1988).

Although no survey estimates are available for other bark beetle species in Yellowstone Park, surveys of adjacent areas showed only the DFB was increasing, whereas spruce beetle (*D. rufipennis* Kirby) (SB) infestation was light (Knapp and others 1988) and pine engraver (*Ips pini* Say) populations had declined (Gibson and Oakes 1989).

METHODS

Canopy fires that caused complete defoliation usually resulted in complete burning or severe scorching of the inner bark, especially in thin-barked species, so that trees with this type of injury were no longer suitable for bark beetle infestation (Amman in press). As a result, our sampling focused on areas where canopy fires did not occur and in adjacent unburned forests. Observations were made in GYA areas covered by four fires (fig. 2): (1) North Fork Fire—Bunsen Peak and Madison River; (2) Snake River Fire—Grant Village; (3) Huck Fire—Rockefeller Memorial Parkway; and (4) the Hunter Fire—Ditch Creek, about 35 miles south of Yellowstone Park. In each area, variable plots (10 ft^2/acre basal area factor) were established in 1989, with five additional plots established in 1990. Plots were mostly at low elevations between 6,725 and 8,000 feet; therefore, trees consisted mostly of lodgepole pine and Douglas-fir. Trees were classified alive or dead, based on the presence or absence of living foliage and the percentage of basal circumference girdled by fire. Mortality by year (1988 to 1990) could still be determined in 1990. Individual trees within the plots were permanently marked in order to follow survival for several years, except in the heavily used Madison River area. Because of the possibility of tags being removed by park visitors, successive observations were made by comparing tree diameter and location in the Madison River plots.

Observations included tree species, diameter at breast height (d.b.h.), degree of fire injury, presence of insect attack, and insect species. Tree injury was measured as the percentage of basal circumference in which the cambium was killed, and percentage crown scorch. Cambium injury was determined by removing small sections of bark and visually inspecting tissues. Crown scorch was ocularly assessed and expressed as the percentage of the prefire crown volume killed. Boring frass expelled from the bark was the usual sign of insect infestation. Some bark was removed from trees infested by insects so that insects could be identified. All insect observations were made on the lower 7 feet of the trees. Insects attacking trees were classified according to whether they were primary or secondary bark beetles, wood borers, or other insects. The preliminary observations of tree mortality also were compared to mortality predicted by the Ryan and Reinhardt model (1988).

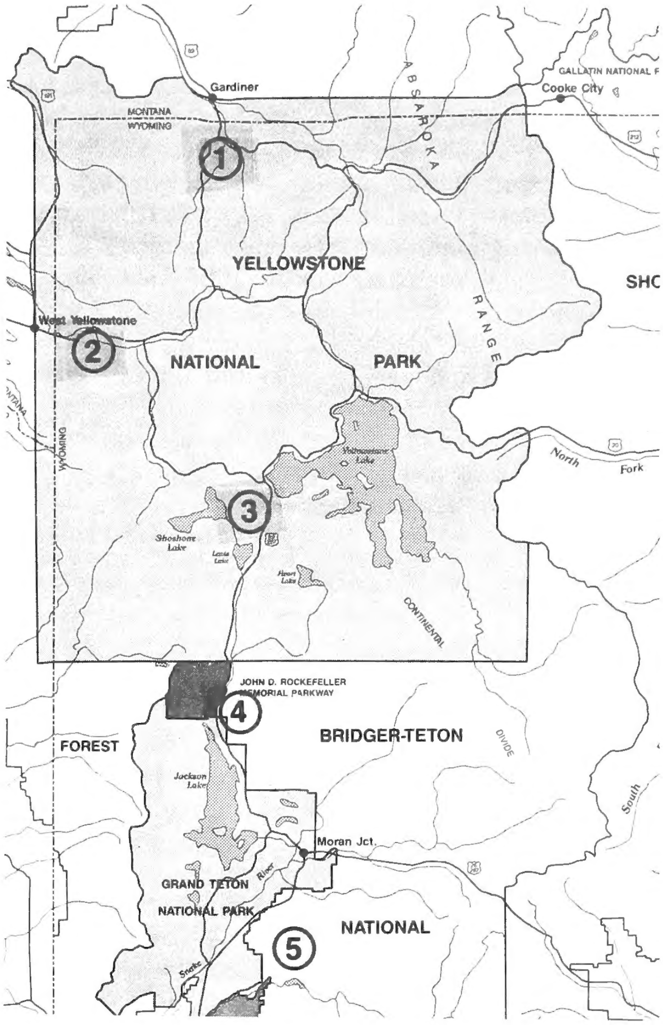

Figure 2—Study plot locations in Yellowstone National Park and vicinity: (1) Bunsen Peak, (2) Madison River, (3) Grant Village, (4) Rockefeller Memorial Parkway, (5) Ditch Creek.

RESULTS AND DISCUSSION

The small populations of bark beetles in the GYA, coupled with timing of the fires (July to September) in relation to life cycles of bark- and wood-infesting beetles, resulted in no fire-injured trees in our sample being infested in 1988. The SB, DFB, and pine engraver emerge to infest new material in the spring, prior to occurrence of the 1988 fires. The MPB emerges in late July and early August, but few were in the GYA.

Insects infesting trees in 1989 and 1990 ranged from the aggressive *Dendroctonus* (capable of infesting and killing trees) to the nonaggressive wood borers (capable of infesting only severely weakened and dead trees) (table 1).

Lodgepole Pine

Lodgepole pine (*Pinus contorta* var. *latifolia* Engelmann) is the most abundant tree in the samples. In 1989, 24 percent of the 147 lodgepole were infested by insects, increasing to 44 percent in 1990 (fig. 3). The pine engraver accounted for most of this infestation (71 percent of infested trees). Of the trees infested, only 5 percent had not been scorched by fire. Most commonly, trees infested by the pine engraver had greater than 80 percent basal girdling by fire (fig. 4). Many of these trees showed little evidence of scorch and looked healthy except for boring frass made by the beetles. However, upon closer inspection, the trees were completely girdled at the base by a light ground fire. Based on the 1990 survey data, 49 percent of the original trees (infested and uninfested) were classified dead (table 2). Observed mortality is about two-thirds of that predicted by Ryan and Reinhardt (1988). It often takes in excess of 2 years for all foliage to die on trees that are completely girdled at the base. Given the slow rate of death associated with basal girdling and the current level of insect activity, additional mortality is expected. Dead trees were somewhat (but not significantly) smaller than live trees (d.b.h. = 8.9 inches vs. 10.3 inches). Given the extremely low bark thickness to diameter ratio for lodgepole (compare Ryan and Reinhardt 1988), it is not surprising that tree diameter was not significantly different between alive and fire-killed lodgepole pine.

The large number of trees infested by pine engraver was not surprising because these beetles are able to reproduce in wind-broken material (including large branches) and in decadent trees near death (Sartwell and others 1971). Mature forests always seem to have plenty of such material available. Although not causing noticeable tree mortality in 1988, the engraver was present in sufficient numbers to infest many fire-injured lodgepole pine in the spring of 1989.

The mountain pine beetle was observed in only seven trees, all in the Hunter Fire on the Bridger-Teton National Forest. MPB was mixed with pine engraver and the twig beetle (*Pityophthorous confertus* Say) in these trees, a common occurrence when MPB populations are at a low level (Schmitz 1988).

Observations over the years suggest that MPB is not strongly attracted to fire-scorched trees, so few trees probably would have been infested even if larger populations of MPB had been present in the GYA. MPB seldom breeds in trees injured or killed by fire in numbers sufficient to cause an increase in the population (Mitchell and Sartwell 1974). Hopkins (1905) found no MPB in fire-injured ponderosa pine in the Manitou Park area of Colorado. Blackman (1931), working on the Kaibab National

Table 1—Bark beetles and wood borers infesting trees in the Greater Yellowstone Area following the 1988 fires

Host	Bark beetles: Primary	Bark beetles: Secondary	Borers	Other
Lodgepole pine	*Dendroctonus ponderosae*	*Ips pini* *Dendroctonus valens* *Pityophthorus confertus* *Pityogenes knechteli*	Buprestidae Cerambycidae	*Trypodendron* sp. *Hylurgops* sp. *Hylastes* sp.
Douglas-fir	*Dendroctonus pseudotsugae*	*Pseudohylesinus* sp.	Buprestidae Cerambycidae	
Engelmann spruce	*Dendroctonus rufipennis*	*Ips pilifrons* *Scierus* sp.	Buprestidae Cerambycidae	Siricidae *Trypodendron* sp.
Subalpine fir			Buprestidae Cerambycidae	

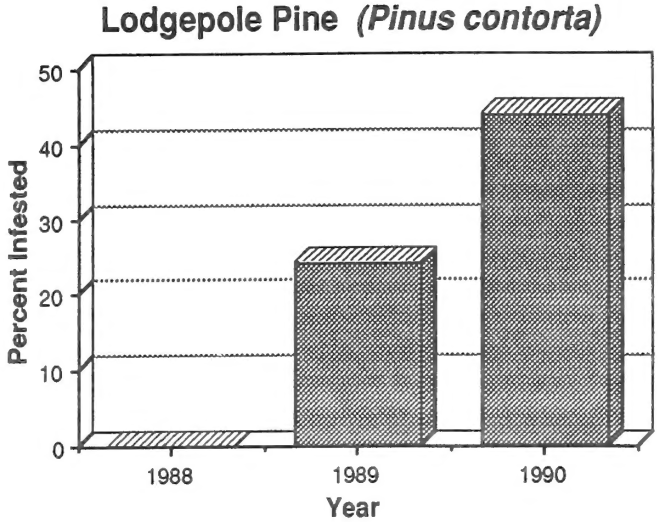

Figure 3—Percentage of lodgepole pine infested primarily by *Ips pini* following the Greater Yellowstone Area fires.

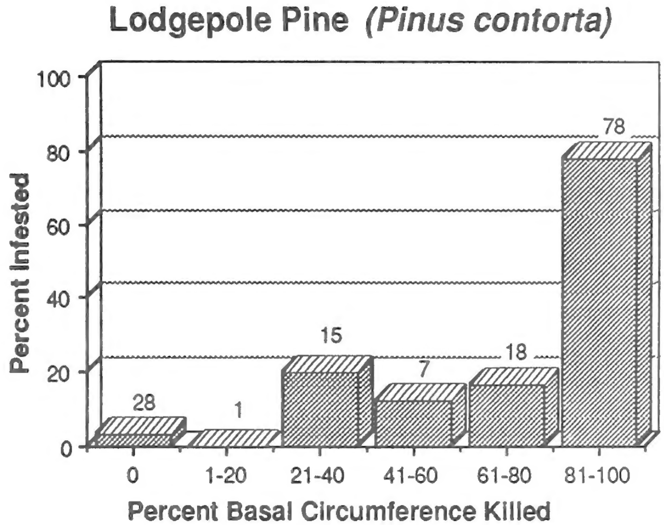

Figure 4—Percentage of lodgepole pine infested primarily by *Ips pini* in relation to basal circumference girdled by fire. Total number of trees in the class appears on top of each bar.

Table 2—Number of plots installed by year, species distribution, total number of trees, proportion infested by insects, and proportion killed by fire but uninfested

Fire	Plots/year 1989	Plots/year 1990	*Abies lasiocarpa* Infested	*Abies lasiocarpa* Killed, uninfested	*Pinus contorta* Infested	*Pinus contorta* Killed, uninfested	*Picea engelmannii* Infested	*Picea engelmannii* Killed, uninfested	*Pseudotsuga menziesii* Infested	*Pseudotsuga menziesii* Killed, uninfested
			Number/proportion							
North Fork	3	4	—	—	6/0.00	/0.00	—	—	95/0.49	/0.10
Snake	0	1	—	—	12/0.50	/0.00	—	—	—	—
Hunter	7	0	8/0.50	/0.50	54/0.58	/0.15	15/0.87	/0.00	4/0.25	/0.00
Huck	9	0	9/0.89	/0.11	75/0.36	/0.00	2/0.50	/0.50	26/0.85	/0.04
Total	19	5	17/0.71	/0.29	147/0.44	/0.05	17/0.82	/0.06	125/0.67	/0.04

Forest in northern Arizona, found MPB were not attracted to fire-scorched trees. He thought the scorched phloem did not offer favorable conditions for beetle offspring. Geiszler and others (1984) observed MPB mostly in trees uninjured or lightly injured by fire, in contrast to pine engraver that occurred in moderately to heavily injured trees. Rust (1933) reported fire-injured ponderosa pine were infested by MPB the first year following a fire in northern Idaho; however, the infestation declined the next year.

The wood borers, both Buprestidae and Cerambycidae, were found occasionally in fire-injured lodgepole pine.

Douglas-fir

Douglas-fir (*Pseudotsugae menziesii* [Mirb.] Franco) was the second most common tree found on the plots. To date, 71 percent of the Douglas-fir (both infested and uninfested) have died—over twice as many as predicted by Ryan and Reinhardt's (1988) model. In thick-barked species, a strong negative relationship between diameter and mortality is normally expected in the absence of severe crown scorch (Ryan and Reinhardt 1988; Ryan 1990). Contrary to expectation, dead trees were not significantly smaller than those still alive. A possible explanation is that Douglas-fir tends to have large lateral roots near the soil surface that are often injured by ground fires (Ryan and others 1988). Thus, unmeasured root injury may have contributed to the higher-than-expected mortality. However, because several of the dead Douglas-firs received minimal heating, insects appear to be responsible for part of the additional mortality.

Of the 125 Douglas-fir examined, 26 percent were infested by insects in 1989, mostly DFB (58 percent

of infested trees) and a few wood borer larvae of both Buprestidae and Cerambycidae. Most infested Douglas-fir in 1989 had 50 percent or more stem girdling by fire (Amman in press). In 1990, infested trees increased to 67 percent of the total (fig. 5), and most of these had 20 percent or more stem girdling. In addition, the number of uninjured trees infested by DFB increased dramatically in 1990, when 46 percent of the 55 trees in this category were infested (fig. 6). In 1989, some Douglas-firs that had needles and limbs completely burned were infested by DFB in the base where the bark was thick enough to protect the phloem from direct fire injury or from drying so excessively that beetles would not construct egg galleries in it. In 1990, DFB infested most of the remaining live trees on the Madison River plots, even though many of these trees would have survived the fire injury. DFB also infested many trees at this site that were not subjected to fire injury, indicating that DFB increased populations in fire-injured trees and readily spread to uninjured trees. Given the current level of insect activity, additional Douglas-fir mortality is expected in 1991.

This appears to be somewhat contrary to observations by Malcolm Furniss (1965), who found DFB infested 88 percent of fire-injured Douglas-fir following a fire in Idaho, but brood survival was low because of pitch invasion of galleries and sour sap condition. He did not report any infestation after the first postfire year. However, Robert Furniss (1941) observed DFB buildup in Douglas-fir in Oregon following a fire in 1933. Beetles subsequently killed large numbers of uninjured trees in 1935 and 1936. Furniss thought DFB were able to increase because frequent fires in the area provided large numbers of injured trees for successive generations, thus allowing the beetles to increase.

Engelmann Spruce

Engelmann spruce (*Picea engelmannii* Parry) constituted a small part of our tree sample, with only 17 trees examined. Currently, spruce mortality is 88 percent—close to that predicted by Ryan and Reinhardt (1988). As expected for a thin-barked species, mortality did not vary by tree diameter. Insects infested 65 percent of the trees in 1989, increasing to 82 percent in 1990 (fig. 7). Of the infested spruce, SB was in 50 percent of them. All infested spruce except one had 81 percent or greater basal girdling by fire. Observations of spruce not on our plots showed the duff around the base resulted in a slow-burning fire that often burned off the roots or so weakened them that some trees were easily blown over by wind. Windthrown spruce with unscorched trunks created an ideal habitat for the SB, which shows a strong preference for windthrown trees (Schmid and Hinds 1974). The small additional infestation that occurred in 1990 is probably because the spruce beetle has a 2-year cycle in the area. Additional mortality is expected when beetles from trees infested in 1989 emerge in 1991.

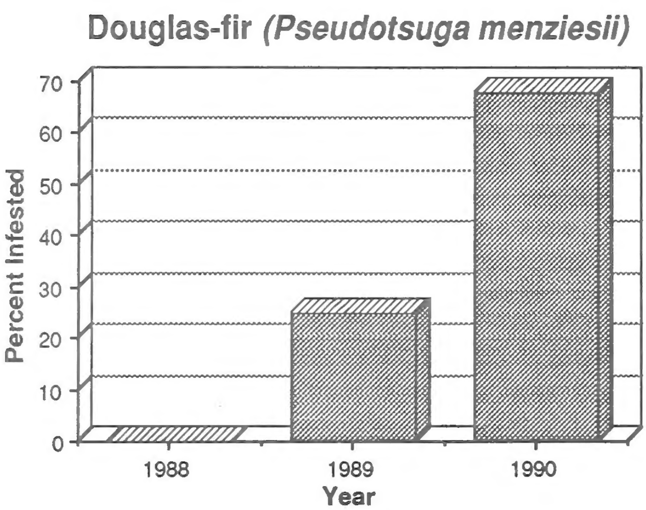

Figure 5—Percentage of Douglas-fir infested primarily by Douglas-fir beetle following the Greater Yellowstone Area fires.

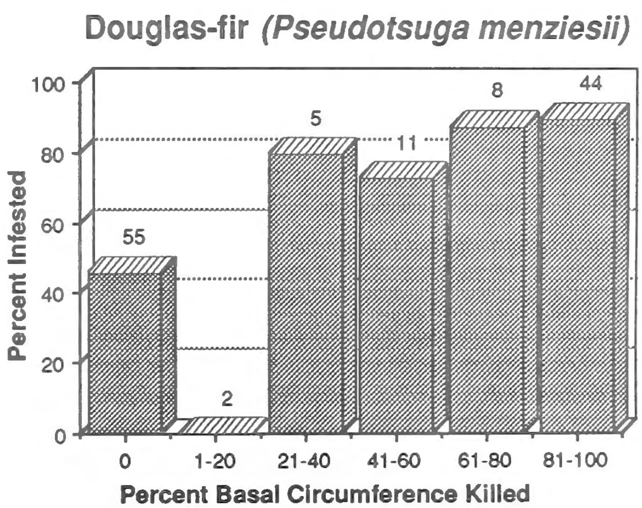

Figure 6—Percentage of Douglas-fir infested primarily by Douglas-fir beetle in relation to basal circumference girdled by fire. Total number of trees in the class appears on top of each bar.

Subalpine Fir

Subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) is noted for its lack of fire resistance, primarily because of its thin bark. Virtually any fire vigorous enough to burn on all sides of the tree will cause girdling, followed by sloughing of the dead bark. All 17 subalpine firs died following the fires. Ryan and Reinhardt's (1988) model accurately predicted the fate of these trees. Wood borers (Buprestidae and Cerambycidae) infested 35 percent of the subalpine fir in the sample in 1989 (fig. 8). Infestation increased to 71 percent in 1990. All of the trees had suffered 81 percent or greater basal girdling by fire; most of the bark was badly burned and not conducive to bark beetle infestation. Borer infestation was limited to bark that remained tightly attached to the wood.

CONCLUSIONS

The 1988 fires in the Greater Yellowstone Area killed many trees outright. Many more were subjected to sublethal injuries resulting in increased susceptibility to insect attack. Still other trees escaped fire injury but are exposed to the spread of insect attack from nearby injured trees. Because it is often difficult to adequately assess all fire injuries, the extent to which insects are primary contributors to death (as opposed to being opportunists attacking mortally injured trees) is often unclear. Additional research is needed to focus on the physiological responses of fire-injured trees and their relationships with insect ecology.

Although our sample of trees is small when the total number of trees in the GYA is considered, these observations suggest an increasing trend for bark beetle infestation of both fire-injured and uninjured trees for 1991 and probably beyond. Preliminary indications are that existing models for predicting fire-caused mortality of these species should be used with caution following wildfires, particularly in areas of uneven burning near the edges of more severely burned forests.

REFERENCES

Amman, Gene D. [In press]. Bark beetle-fire associations in the Greater Yellowstone Area. In: Proceedings of the Fire and the Environment Symposium; 1990 March 20-24; Knoxville, TN.

Bevins, C. D. 1980. Estimating survival and salvage potential of fire-scarred Douglas-fir. Res. Note INT-287. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Blackman, M. W. 1931. The Black Hills beetle. Tech. Publ. 36. Syracuse, NY: Syracuse University, New York State College of Forestry. 77 p.

Fellin, David G. 1980. A review of some interactions between harvesting, residue management, fire, and forest insects and diseases. In: Environmental consequences of timber harvesting in Rocky

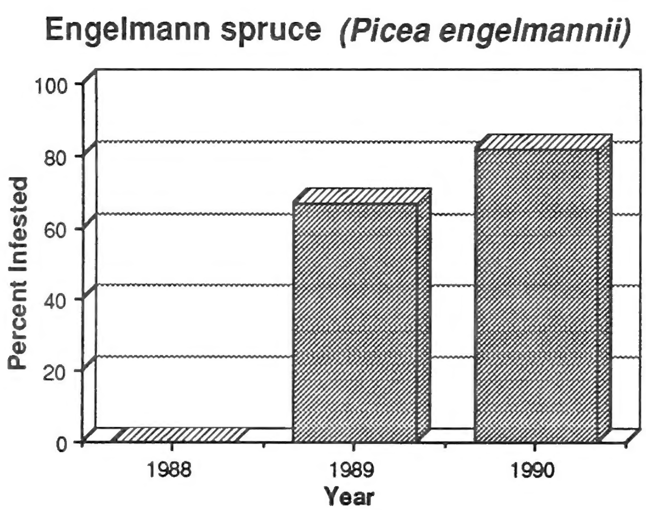

Figure 7—Percentage of Engelmann spruce infested primarily by spruce beetle following the Greater Yellowstone Area fires.

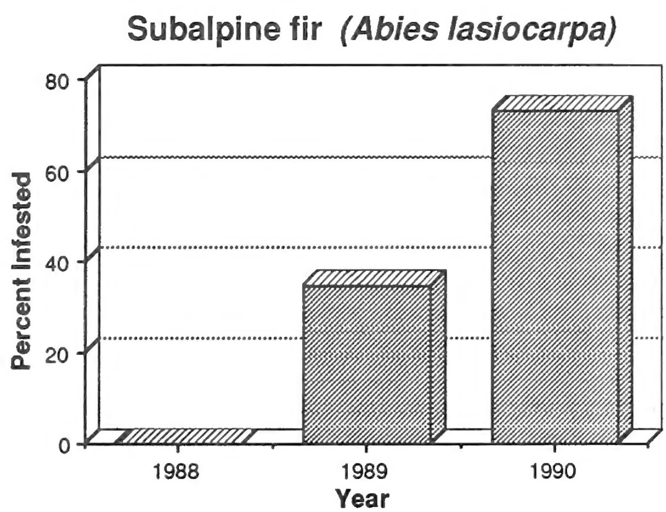

Figure 8—Percentage of subalpine fir infested by wood borers following the Greater Yellowstone Area fires.

Mountain coniferous forests: Symposium proceedings; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 335-414.

Ferguson, E. R.; Gibbs, C.; Thatcher, R. C. 1960. "Cool" burns and pine mortality. Fire Control Notes. Washington, DC: U.S. Department of Agriculture, Forest Service. 21(1): 27-29.

Furniss, M. M. 1965. Susceptibility of fire-injured Douglas-fir to bark beetle attack in southern Idaho. Journal of Forestry. 63: 8-11.

Furniss, R. L. 1941. Fire and insects in the Douglas-fir region. Fire Control Notes. 5: 211-213.

Furniss, R. L.; Carolin, V. M. 1977. Western forest insects. Misc. Publ. 1339. Washington, DC: U.S. Department of Agriculture, Forest Service. 654 p.

Geiszler, D. R.; Gara, R. I.; Littke, W. R. 1984. Bark beetle infestations of lodgepole pine following a fire in south central Oregon. Zeitschrift für angewandte Entomologie. 98: 389-394.

Gibson, K. E.; Oakes, R. D. 1987. Mountain pine beetle status report, Northern Region, 1986. For. Pest Manage. Rep. 87-7. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 17 p. plus maps.

Gibson, K. E.; Oakes, R. D. 1988. Bark beetle conditions, Northern Region, 1987. For. Pest Manage. Rep. 88-4. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 21 p. plus maps.

Gibson, K. E.; Oakes, R. D. 1989. Bark beetle conditions, Northern Region, 1988. For. Pest Manage. Rep. 89-7. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 20 p. plus maps.

Hopkins, A. D. 1905. The Black Hills beetle. Bull. 56. Washington, DC: U.S. Department of Agriculture, Bureau of Entomology. 24 p.

Knapp, A.; Weatherby, J.; Hoffman, J.; Kalve, V.; LaMadeleine, L. 1988. Forest insect and disease conditions, Intermountain Region, 1988. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, State and Private Forestry, Forest Pest Management. 31 p.

Martin, R. E. 1963. A basic approach to fire injury of tree stems. Proceedings Tall Timbers Fire Ecology Conference. 2: 151-162.

Miller, J. M.; Keen, P. 1960. Biology and control of the western pine beetle. Misc. Publ. 800. Washington, DC: U.S. Department of Agriculture. 381 p.

Mitchell, R. G.; Martin, R. E. 1980. Fire and insects in pine culture of the Pacific Northwest. In: Martin, R. E.; [and others], eds. Proceedings, 1980 sixth conference on fire and forest meteorology. Washington, DC: Society of American Foresters: 182-190.

Mitchell, R. G.; Sartwell, C. 1974. Insects and other arthropods. In: Cramer, O. P., ed. Environmental effects of forest residues management in the Pacific Northwest: a state-of-knowledge compendium. Gen. Tech. Rep. PNW-24. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: R-1 to R-22.

Peterson, D. L. 1985. Crown scorch volume and scorch height: estimates of postfire tree condition. Canadian Journal of Forestry. 15: 596-598.

Peterson, D. L.; Arbaugh, M. J. 1986. Postfire survival in Douglas-fir and lodgepole pine: comparing the effects of crown and bole damage. Canadian Journal of Forest Research. 16: 1175-1179.

Peterson, D. L.; Arbaugh, M. J. 1989. Estimating postfire survival of Douglas-fir in the Cascade Range. Canadian Journal of Forest Research. 19: 530-533.

Peterson, D. L.; Ryan, K. C. 1986. Modeling postfire conifer mortality for long-range planning. Environmental Management. 10(6): 797-808.

Rust, H. J. 1933. Final report on the study of the relation of fire injury to bark beetle attack in ponderosa pine (Tubb's Hill Burn). Coeur d'Alene, ID: U.S. Department of Agriculture, Bureau of Entomology, Forest Insect Field Station. 22 p.

Ryan, K. C. 1982. Evaluating potential tree mortality from prescribed burning. In: Baumgartner, D. M., ed. Site preparation and fuels management on steep terrain: Proceedings of symposium; 1982 February 15-17; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension: 167-179.

Ryan, K. C. 1990. Predicting prescribed fire effects on trees in the Interior West. In: Alexander, M. E.; Bisgrove, G. F., tech. coords. The art and science of fire management; 1989 October 24-27; Kanaskis, AB. Inf. Rep. NOR-X-309. Edmonton, AB: Forestry Canada: 148-162.

Ryan, K. C.; Frandson, W. H. 1991. Basal injury from smoldering fires in mature Pinus ponderosa Laws. International Journal of Wildland Fire. 1: 109-119.

Ryan, K. C.; Peterson, D. L.; Reinhardt, E. D. 1988. Modeling long-term fire-caused mortality of Douglas-fir. Forest Science. 34: 190-199.

Ryan, K. C.; Reinhardt, E. D. 1988. Predicting postfire mortality of seven western conifers. Canadian Journal of Forest Research. 18: 1291-1297.

Sartwell, C.; Schmitz, R. F.; Buckhorn, W. J. 1971. Pine engraver, *Ips pini*, in the Western States. For. Pest Leafl. 122. Washington, DC: U.S. Department of Agriculture, Forest Service. 5 p.

Schmid, J. M.; Hinds, T. E. 1974. Development of spruce-fir stands following spruce beetle outbreaks. Res. Pap. RM-131. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 16 p.

Schmitz, Richard F. 1988. Understanding scolytid problems in lodgepole pine forests: the need for an integrated approach. In: Payne, T. L.; Saarenmaa, H., eds. Integrated control of scolytid bark beetle: Symposium proceedings; IUFRO Working Party and XVII International Congress of Entomology; 1988 July 4; Vancouver, BC. Blacksburg, VA: Virginia Polytechnic Institute and State University: 231-245.

Wagener, W. W. 1961. Guidelines for estimating the survival of fire-damaged trees in California. Misc. Pap. 60. Washington, DC: U.S. Department of Agriculture, Forest Service. 11 p.

Wyant, J. G. 1986. Fire induced tree mortality in a Colorado ponderosa pine/Douglas-fir stand. Forest Science. 32: 49-59.

✩U.S. GOVERNMENT PRINTING OFFICE: 1991 -573 -041/41012

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Printed on Recycled Paper

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)